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High-Energy Laser Weapons for the Fleet

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A historical retrospective of Navy high-energy laser (HEL) development is combined with a comprehensive discussion of mission-related motivations for ultimate operational usage of HEL weapons in the Fleet. Discussion is provided that highlights the changed circumstances over the past two decades that have renewed Navy interest in directed energy weapon opportunities. The unique characteristics of HELs relative to both today's operational needs and future Navy requirements are reviewed. Current status and future prospects for particular laser device development paths as well as special technology challenges (beam control) facing the eventual delivery of practical and useful weapon systems are discussed. These issues are all addressed from the perspective of the authors, sea-experienced naval officers and seasoned program managers, who have held or currently hold full accountability for Navy directed energy weapon progress.

KEYWORDS: Directed energy weapons, Future prospects for Navy laser weapons, High-energy lasers, History and status of Navy laser weapons, Navy

1. Foreword

The threat scenario dominating Fleet defense in the 1970s and 1980s was saturation air raids from the Soviet Union. The issues today are more amorphous and span a broader spectrum that embraces force protection in port as well as hemispheric ship defense on the high seas. The threat has become diffused, diverse, and frequently unpredictable. The Navy has recognized the latent promise of directed energy weapons (DEWs) in countering such fresh menace, as well as the ability of electromagnetic weaponry to reach out against a wide array of enemy forces and hardware with both defensive and unique offensive capabilities. Today the threat includes structured foreign governments as well as unstructured tribalism, terrorism, and fanaticism. The prospect of weapons that can be "adjusted" to provide variable intensity proportional to a threat's changing deadliness offers possible defensive responses ranging from nonlethal discouragement to abrupt and surgical kill. In an era when the enemy is unusually diabolical in exploiting open societies and their unique freedoms, when he is willing to employ suicide as a tactic, and when the world's press can influence political

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decision making, defensive flexibility must be sought that minimizes the chances of socio–politico–military entrapment from either inadvertent or accidental operational error. Every rational attempt must be made to sidestep the tragedy of unnecessary collateral damage or unintended consequence. DEW coupled with modern control mechanisms can provide just such flexibility.

2. Background

During the mid-1970s and early 1980s the Navy conducted a vigorous development program in high-energy lasers (HELs). This program proceeded with success after success and proved that high-power beams could be delivered from laser devices and out of beam directors in support of Navy mission areas such as anti-ship missile defense, close-in air attack, and either asymmetrical surface warfare or overhead defense. Indeed, by the early 1980s, the Navy led all other Services in demonstrating high power capability with its Mid Infra-Red Advanced Chemical Laser (MIRACL). This laser used storable reactants to produce a weapon-power level beam and established records still standing for irradiance (power per unit area) delivered at range and fluence (energy per unit area) delivered on target through its Sea Lite Beam Director (SLBD). Prior to MIRACL the Navy conducted test demonstrations that employed less powerful experimental laser beam director systems including the Navy–Advanced Research Projects Agency (ARPA) Chemical Laser (NACL) and the Navy Pointer/Tracker (NPT). Even with these less powerful systems the Navy was able to produce a series of impressive shoot downs of operational aircraft and missiles. The results of this series of tests allowed the Navy laser weapon system developers to validate their ability to track dynamic targets, place and maintain a hot beam on an aim point, and destroy several threat-representative vehicles both subsonic and supersonic. All these trials, however, were in escort defense scenarios (side shots), and this meant that none of these tests involved a threat that was flying directly toward the laser beam director. The program, though declared an experimental success by Navy Secretariat research administrators at the time, was zero-budgeted in FY'84, and the equipment, already scheduled for installment at White Sands Missile Range (WSMR), became a national asset that continued to be operated in support of Defense Advanced Research Projects Agency (DARPA), Strategic Defense Initiative Organization (SDIO) [later Ballistic Missile Defense Organization (BMDO), now Missile Defense Agency (MDA)], Air Force, and Army technology interests. It remains in use today, on Navy loan to the Army, still the most powerful laser in the Western world, 25 years after its first module lased and validated the engineering feasibility of weapon-power level lasers (Fig. 1).

So, why aren't there laser weapons in our Fleet if all the technical signs were so good so long ago? And, if there are good and sufficient reasons why not, why are we stirring ourselves once again to develop such weapons for naval applications? In short, what is different today? This article is a brief status report and bill of expectations for a reconstituted Navy effort now underway to develop laser weapons for Fleet use in a much-changed world.

3. Discussion

Not a weapon exists that does not have its limitations whether because of environmental conditions (heavy sea state, rain, fog, electrical storms), tactical constraints (geometry, geography, performance bounds, electromagnetic interference), or political implications (collateral damage, "tribal" arousal, differing cultural perspectives). Yet we depend universally on the capabilities of weaponry with their parochial deficiencies to help us prevail in

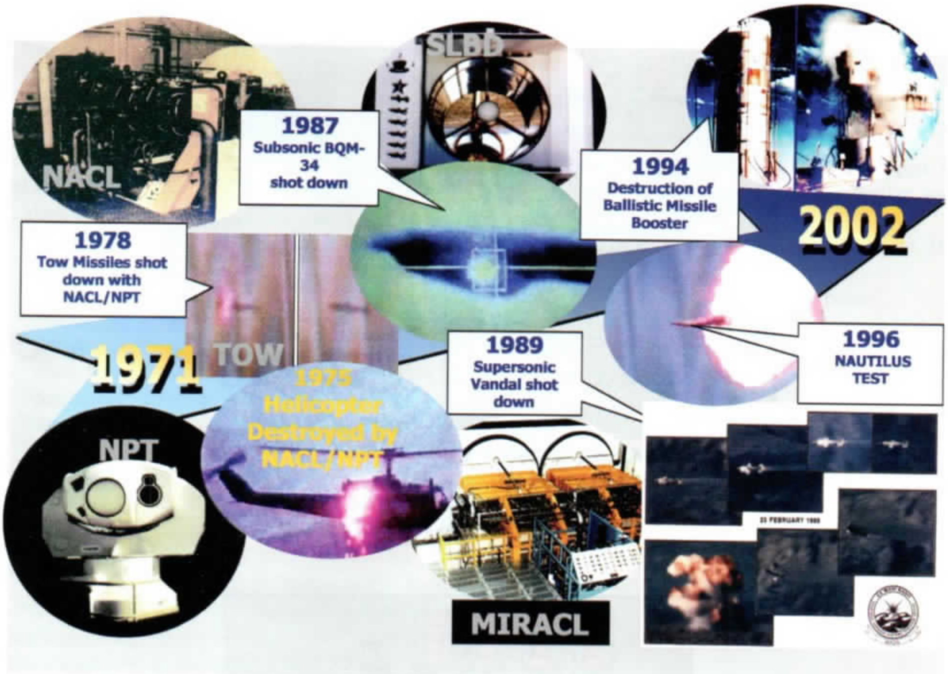

Fig. 1. U.S. Navy HEL experience.

maintaining battlefield dominance and global peace. How are we to avoid being undone at the wrong moment by the equipment roulette wheel of chance and the unavoidable realities of life? Routinely, we strive to educate and train our people to understand the weaknesses as well as the strengths of their equipment and to be able to use their creative minds to plan, both strategically and tactically, so that we are able to sidestep any known vulnerability that might befall us. Then, we design, build, and operate combat systems so that we and the equipment, in combination, present mutual attributes that form a wall of strength with few to no openings an enemy can capitalize upon.

The fresh advent of directed energy weaponry permits this sensible tradition to continue and expand. We should be able to inject new capabilities within the electromagnetic spectrum without loss of our conventional capabilities to yield a more balanced strength across the board. Global defense requirements are today becoming less *threat driven* than *capabilities driven* because the threat is not dogmatically shaped. A broad response capacity must be available to cope with the unexpected. We have moved from the massed threats and saturation raids of the Cold War to the innovative generics and surprise "low tech" creations springing out of parochialism, fanaticism, and the murderous horrors of terrorism. We must be able to cope with essentially anything.

For the Navy, the promise of multimegawatt power from a ship's electric plant in the face of this new global confrontation is what is different today (Figs. 2 and 3).‡ Laser weapons have the potential to offer antisatellite protection and ballistic missile defense or

‡Courtesy Jeffrey Koleser, Naval Sea Systems Command, Washington, DC.

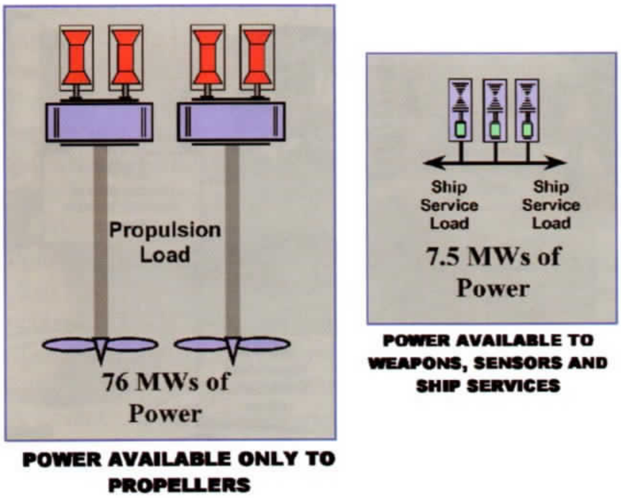

Fig. 2. Conventional power system.

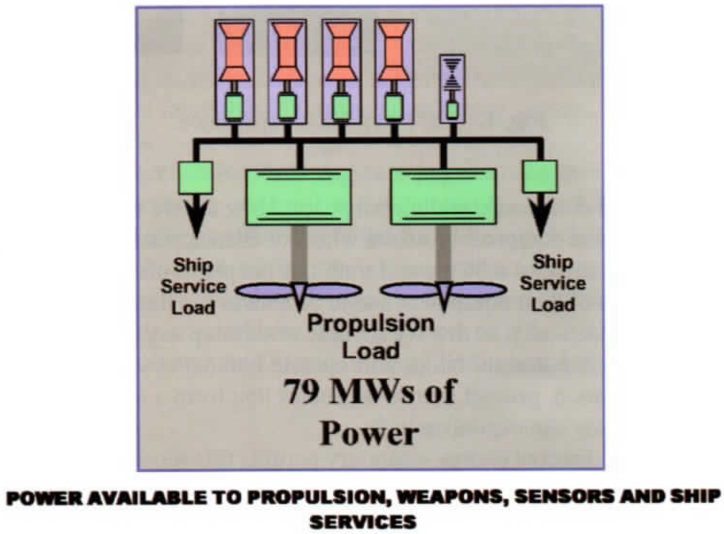

Fig. 3. Integrated power system.

to be "throttled-down" to handle hard-to-discern, short-timeline targets.[§] The Navy can provide mobile platforms (fighting ships) that can be positioned or repositioned to protect our own or allied forces and populations from multiple forms of surveillance and attack. Using proportional kill intensity ranging from nonlethal discouragement to catastrophic stoppage against close-in threats that could appear suddenly in the littorals or, as we have

[§]Defense Science Board Task Force on High Energy Laser Weapon Applications, June 2001, OUSDAT,L; page xi, Table entry: Ground-Based Laser for Space Control.

seen with the *USS Cole*, in port, permits a "tuned to circumstance" defense. This spectrum of capability further reinforces the logic argument for aggressive development of speed-of-light weapons. Such weapons can be a new element both in our maintaining dominance on the battlefield and in our carrying an improved shield for force protection in port or underway. In combination with our array of existing weaponry we can become less vulnerable to novel attack.

3.1. History

A complete accounting covering the historical development of HEL would be too intricate to present here. Briefly, the Navy program began among great secrecy and ambitious expectations in the late 1960s and early 1970s. High-power, continuous wave and pulsed lasers were sponsored at Pratt and Whitney and AVCO, Everett, as experimental devices. Three identical designs known as the TriService Laser (TSL) were built by AVCO, Everett (now Textron), one for each military service. The Navy followed this initial thrust with its Baseline Demonstration Laser (BDL), which used hydrogen fluoride (HF) and validated high-power capability. Subsequently, with cooperative support from ARPA a higher-power, water-cooled deuterium fluoride (DF) NACL was constructed and validated. (Both BDL and NACL were TRW, now Northrop Grumman, designs.) A beam director for NACL was designed and built by Hughes (now Raytheon) called the NPT. It was this combination of NACL and NPT emplaced at the TRW Capistrano Test Site (late 1970s) that shot down a "pop-up" UH-1 helicopter and later TOW (tube launched, optically tracked, wire-command link guided missile weapon system) missiles in the first serious challenge of both operational aircraft and modern ordnance by a light beam.

While the NACL–NPT land-based experiment was being planned and tests conducted, the Navy had under simultaneous development an even more powerful DF design, the MIRACL, a true weapon-power level device (TRW). This was a regeneratively cooled configuration that capitalized on the experience established in the operation of both BDL and NACL. The program to conduct this experiment was designated SEA LITE (System Engineering and Analysis of Lasers In a Test Environment), which also included a companion beam director, the SLBD (again, Raytheon). Never before was so much power available from photon-emitting and transferring hardware. The MIRACL was used to conduct damage and vulnerability data collection and, ultimately, with the SLBD was moved to the High Energy Laser System Test Facility (HELSTF) at WSMR (Fig. 4), where it performed a supersonic VANDAL (Talos missile drone) shoot down and helped in several other support tests of multiservice interest (e.g., a U.S. Air Force ballistic missile booster shot) (Fig. 1). This first weapon-power level experimental system, designed, owned, and operated by the Navy is currently on loan today to HELSTF, an Army organizational activity, part of Space and Missile Defense Command (SMDC), with MIRACL–SLBD in rehabilitation and upgrade for renewed Navy testing; see below.

3.2. Present status

So, again, why the hiatus in Navy HEL weapon development? RADM Michael Mathis, USN, former commander of the Naval Surface Warfare Center at the Naval Sea Systems Command who worked in HEL development earlier in his career, states, "The parting shot was a test that . . . (in the mid 1990s) . . . was not particularly successful." The hard fact is that the prime interest from a Navy self-defense mission view is an unarguable demand to destroy an incoming target on a radial course. This is the most difficult scenario in the military

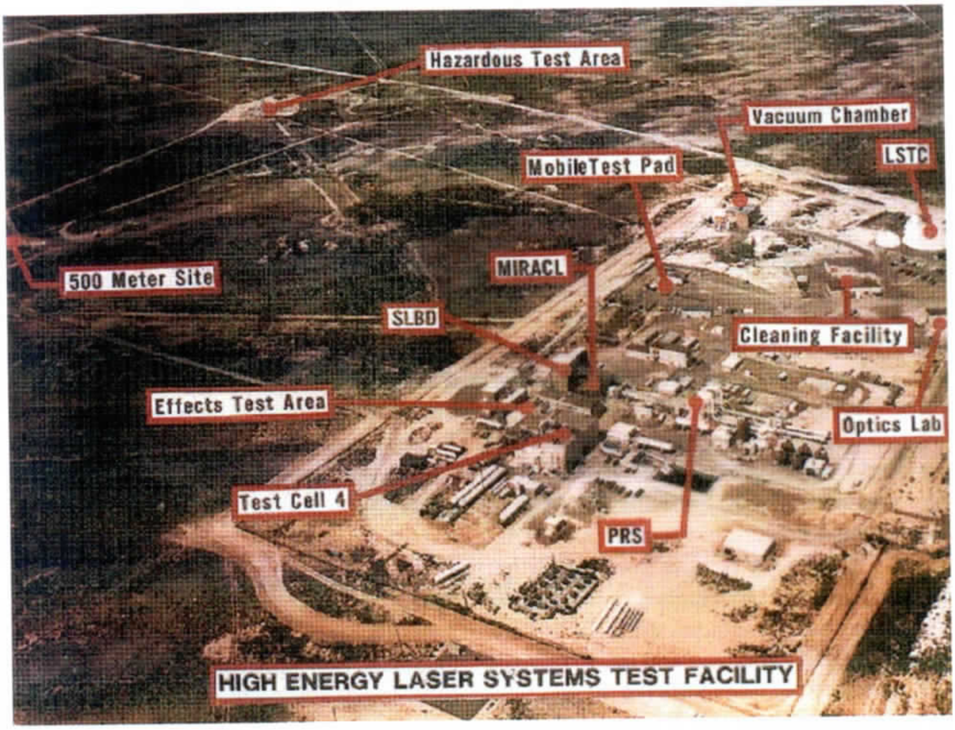

Fig. 4. WSMR test facility.

community for laser weapons since the target aspect presents a very small "footprint." The target could be in sea spray (perhaps kicking up sea spray); the trajectory is not smooth, and so the laser aim point dynamics are difficult; and the intervening atmosphere through which the beam is passing, perhaps with minimal slew rate, can compromise beam quality on target. With small to no slew rate the beam tends to heat up the air molecules in its path causing a diffusing effect ("thermal blooming") that can compromise beam lethality. Special techniques using adaptive optics can be used to ameliorate this effect. Clearly, low-aspect-angle target testing is an important milestone in bringing lasers into operational fruition for the Fleet; this makes it a significant element in current Navy test planning.

The testing at WSMR/HELSTF in the mid-1990s that did not provide the hoped for results against flying targets failed primarily because of inadequate tracking against a desert background (not usually considered to be a critical Navy issue) along with insufficient beam stability and accuracy in maintaining the laser beam's aim point upon the target. (System size and cost estimates at that time also discouraged continued operational consideration of this chemical laser configuration by Navy decision makers.) Comprehension of these complexities on Capitol Hill has led recently to Congressional support of a renewed effort titled HEL–LATT (High Energy Laser–Low Aspect Target Tracking), which is concentrating on modification of the tracking and beam control algorithms to provide improved beam stability and aim point maintenance. The MIRACL–SLBD equipment is being (prudently) upgraded with associated software changes, and so testing against increasingly difficult targets on incoming radial paths can be performed. Success in the planned three phases of testing over a three-year interval should yield assurance that the beam control problem can be handled and further justify additional investment in high-power lasers more compatible with future naval ship design.

3.3. Future prospects

Until recently only chemical lasers were thought to be scalable to the high power levels needed to create a weapons class laser. However, recent advances in free-electron lasers (FELs) and solid-state lasers (SSLs) have demonstrated that these lasers may also be able to scale to the appropriate power levels to inflict the damage needed to stop a hostile target. These advances, combined with the excess power that will be available on the all-electric ships, provide a good prospect for a marriage of convenience between modern ordnance and advanced power-generating machinery (Fig. 5).

The Navy has expressed interest in both of these technologies but is primarily interested in the FEL because of its perceived ability to scale to extremely high power levels. The FEL operates by converting kinetic energy stored in the form of a relativistic electron beam into electromagnetic energy at optical wavelengths. The electron beam is sent through a device with a fixed periodic magnetic field (a wiggler). This field combined with the optical field inside the laser cavity causes the electrons to "wiggle," producing light. The FEL is one of the very few lasers whose operating wavelength can be tuned. The wavelength that the laser operates at can be adjusted by changing the energy of the electron beam, by changing the strength of the magnetic field inside the wiggler of the FEL, or by changing the spacing or periodicity of the fixed magnetic field inside the wiggler. Unlike the HELs of the past that operated at fixed wavelengths, the fact that FELs are frequency tunable allows the developer to design the laser so that it can be used at an optimal frequency for atmospheric propagation in the maritime environment. This capability is one of the breakthrough qualities that justify a renewed development thrust for Navy DEWs. Of course, these benefits will also require

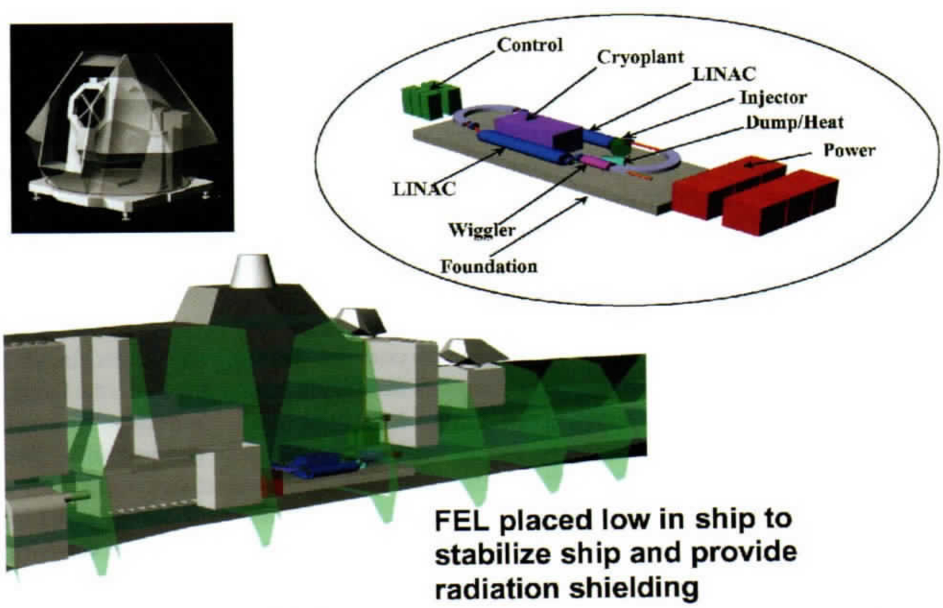

Fig. 5. Notional FEL ship installation.

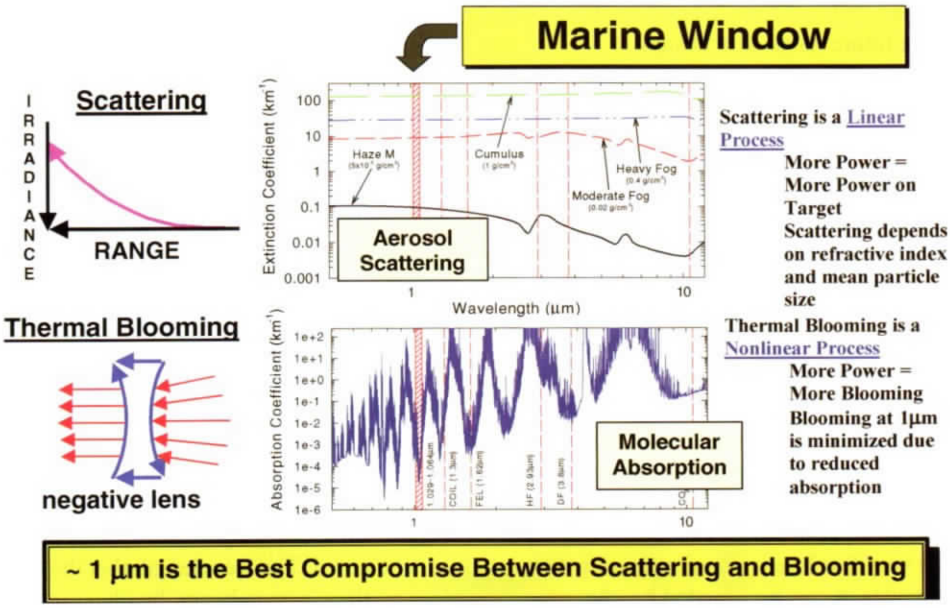

Fig. 6. Transmission windows.

optics that can operate at multiple wavelengths. Either broadband optics, gratings techniques, or several optics that can be mechanically selected as required are possible options. Beyond the fundamental need for superior tracking ability along with precision laying and maintaining of the beam upon the incoming target, there are performance tradeoffs available from selecting optical wavelength. Moving from 3.8-μm (DF chemical laser) to shorter wavelengths, e.g., approximately 1 μm, can offer substantial reduction in energy absorbed by the atmosphere, resulting in a significant reduction in thermal blooming effects. This reduction in absorption can more than compensate for the corresponding degradation from scattering that is associated with the shorter wavelengths (Figs. 6 and 7). Reducing wavelength also has its limits since mirror imperfections and producibility become increasingly difficult to manage as wavelength becomes smaller. The design interactions with anticipated operational usage, not surprisingly, involve both engineering and warrior compromises.

Some SSLs, though not tunable, also operate at frequencies that are optimal for propagating through the maritime environment. SSLs are just now being scaled to power levels that can be considered "weapons class" and may be available for operational use on ships and aircraft this decade (Fig. 8).

Efforts are underway in SSLs that attempt to combine beams from several lasers to form a single coherent beam at the target. Work is also underway to overcome the thermal management problems that plague SSLs, and improved methods of cooling are offering hope that high-power SSLs are feasible. When successful, SSLs offer the prospect of modular design that could lend itself to retrofit of older ships with modern laser weaponry.

Thus, a natural branching appears to occur for future operational applications, with FELs likely to be aboard large capital ships and new construction for very high power capability, while SSLs seem destined for smaller ships, retrofit, and lower power installations.

The second reason for the tremendous renewed interest by the Navy is, as previously remarked, the development of electric drive and integrated power systems for future Navy

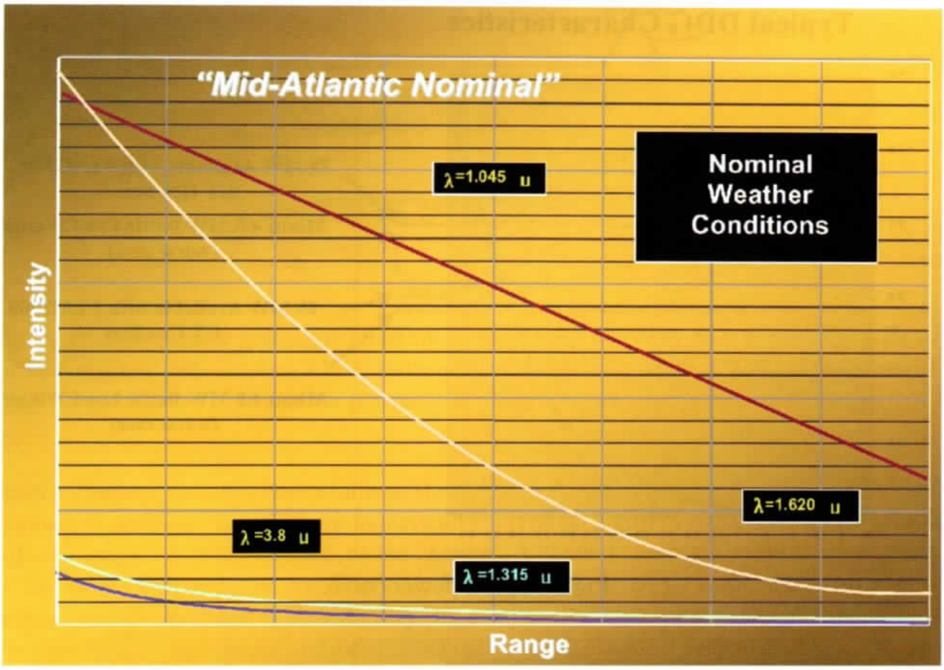

Fig. 7. Intensity vs range.

Fig. 8. SSL destroyer concept.

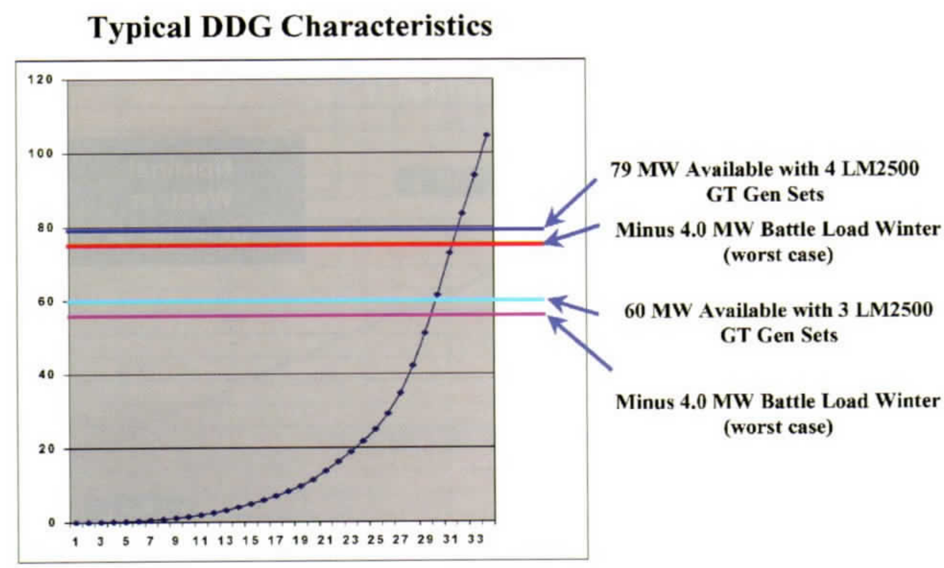

Fig. 9. Speed-power curve.

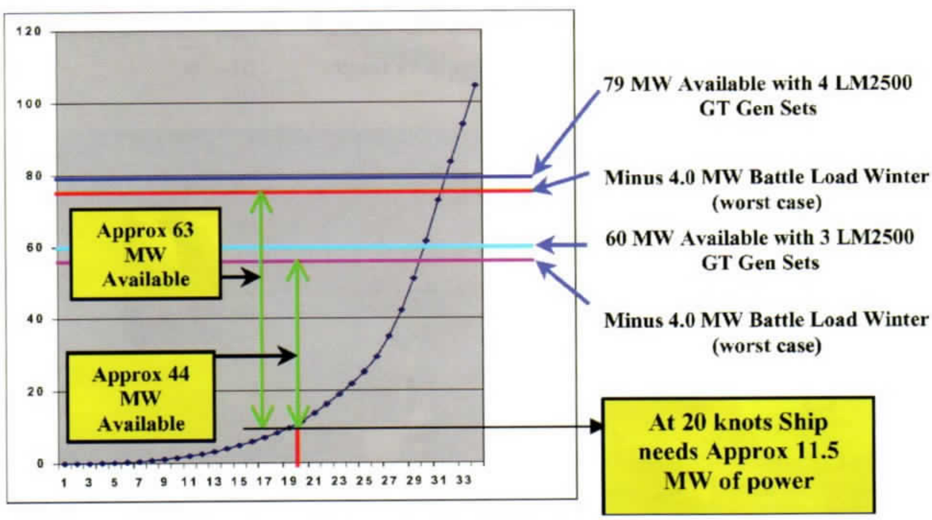

Fig. 10. Speed-power curve: power at 20 kn.

ships. These ships will have tens to hundreds of megawatts of power available for the combat systems. This will remove the requirement for large capacitor banks and batteries and allow use of electrically powered lasers directly from the power supply system of the ship (Figs. 9–12).¶

An unusual property that a HEL system brings to a Navy platform is the unprecedented ability to conduct visual identification of unknown targets at substantial ranges using the

¶Courtesy Jeffrey Koleser, Naval Sea Systems Command, Washington, DC.

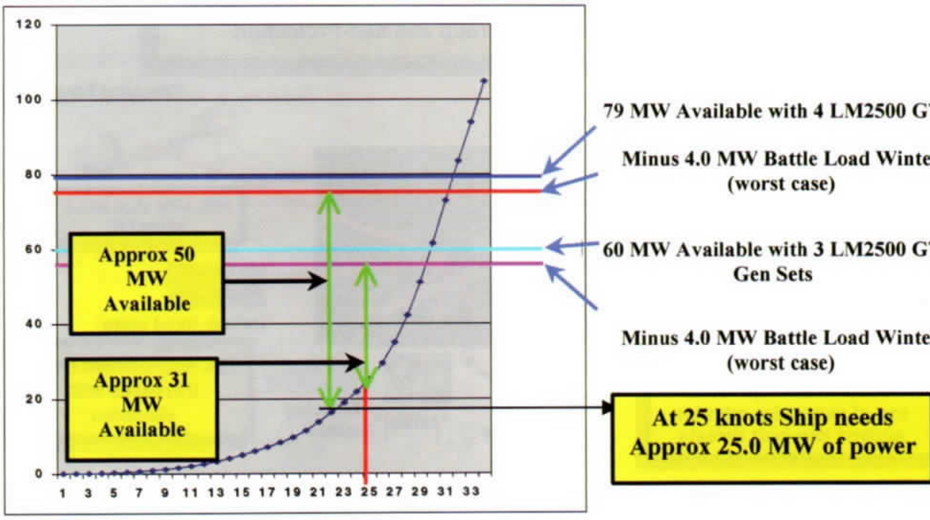

Fig. 11. Speed-power curve: power at 25 kn.

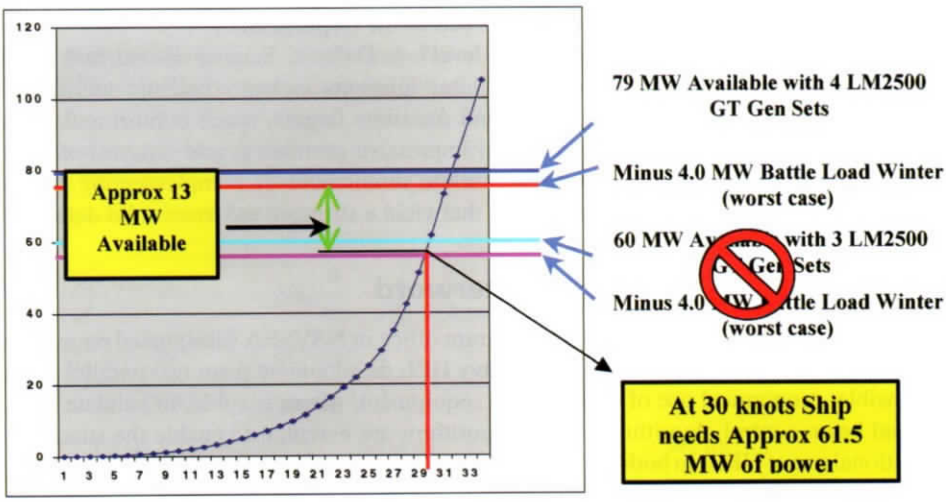

Fig. 12. Speed-power curve: power at 30 kn.

beam director as a telescope. The surgical strike capability mentioned earlier in this article is useful only if the strike is against enemy targets. Being able to visually identify a target from imagery at the engagement range of the weapon is a significant improvement over conventional weapon systems.

Additional benefits that can accrue to the Navy from installation of DEWs include target-sensitive damage/kill effect, "bottomless" magazines, economical cost per kill, modest logistics tail, and the universally acknowledged speed-of-light engagement. For projected surface ship weapons the kill comes in a very few seconds and even less depending on specific target vulnerabilities (Fig. 13).

Air Force and Army programs [airborne lasers and joint Army–Israeli Mobile Tactical High Energy Laser (MTHEL)] have underscored the broad front of progress over the last

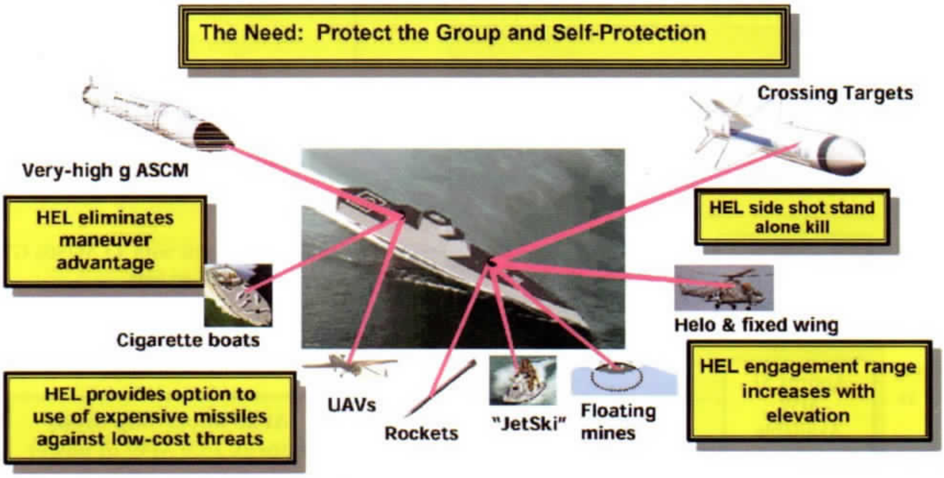

Fig. 13. Force protection and self-defense.

decade with the Department of Defense (DoD) establishing a Joint Technology Office to reinstitute technology development of HELs across the Department.

Why the renewed interest at the DoD level? A Defense Science Board task force after eight months of study reported that laser missions include "ballistic missile defense, air defense, attack against ground and maritime targets, space control and urban operations."** Maturing laser weapons hold impressive promise to add unheard-of abilities to existing conventional weapon suites while simultaneously complementing current combat systems with combined capabilities that yield a stronger and more solid defense.

4. Afterword

The newly reconstituted Navy DEW program office in NAVSEA (designated once again PMS-405) is addressing the challenge of Navy HEL development from two parallel paths: 1) sensible, economical use of existing HEL equipment, where feasible, to validate tracking and beam control algorithms—these algorithms are essential to enable the successful operational use of HELs in both the maritime environment and Navy mission scenarios (particularly self-defense) along with verification of our ability to maintain the laser's aim point on a specific target location; and 2) aggressive development of electrically driven weapon level lasers whose primary power can come directly from a ship's energy sources and whose wavelengths/frequencies are best matched to Navy-expected circumstances (environment/mission). There is renewed enthusiasm in both the senior operational and research communities of the Navy for this fresh thrust. The Chief of Naval Research, RADM Jay Cohen, USN, has written in response to a CINCLANTFLT letter, "I completely share your enthusiasm for the potential of High Energy Lasers to support our forces. The confluence of the availability of hundreds of megawatts of prime power on an 'all electric' warship coupled with advances in electric lasers could make HEL weapons aboard ships a reality

**Defense Science Board Task Force on High Energy Laser Weapon Applications, June 2001, OUSDAT,L; page vii, Scope of the Task Force Work, paragraph one.

this decade. Electric lasers radiate at frequencies that propagate better in the maritime environment. . . ."

Many more technical facets that form the technological details under development and their significant relationships to various operational uses might be presented here. However, the authors prefer at this time, for the initial issue of the *Journal of Directed Energy*, to provide both an historic overview and a current report "from the bridge" with the promise of periodic updates that will inform both the operational and technology communities as the development proceeds in real time.

To maintain its integrity with the operational users, the HEL development community needs to control its promises and emphasize actual delivery of militarily useful results at acceptable cost; it is not impossible to price oneself out of the market. Those serving aboard ship now should recognize that powerful HEL weapon systems will not be installed in the very near term but can be reassured that the Navy is, once again, back in the business of developing DEW for naval applications with a decent sense of urgency. The program staffs in our Services, in our laboratories, and within our industry base are in common alignment on the desired results. Beam propagation and lethality enhancement, pointers and trackers that can function in the operational environment, space and weight reductions, and ruggedness are attributes that cannot be overlooked as development progresses. A step-by-step testing approach that leads from modest to extremely difficult targets with parallel development of high reliability, weapon-power level electric laser devices, combined with appropriate beam control and pointer-trackers that maintain aim point on target, is the Navy's renewed path. The participation of our allies also helps us maintain an international perspective on both developmental engineering and operational usage while, in addition, we work to leverage the efforts of our sister services and the Office of the Secretary of Defense. In the words of VADM G. P. Nanos Jr., USN (Ret.), former Commander, Naval Sea Systems Command (now Director of Los Alamos National Laboratory), remarking on the matter of Navy HEL development, "The Navy is re-engaged."

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